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EXPERIMENTAL DESIGN AND DATA ANALYSIS FOR TELEMETRY PROJECTS: SUMMARY OF A WORKSHOP

VICKY J. MERETSKY

TECHNICAL EDITOR

A workshop on experimental design of telemetry projects and analysis of telemetry data was held at the 1985 Raptor Research Foundation Symposium on Management of Birds of Prey held in Sacramento, California. Speakers stressed the need for careful research design, thorough knowledge of study area and telemetry hardware to be used, flexibility and luck. Design and analysis techniques for mortality, home-range, habitat, migration, predation, dispersal and demography studies were discussed.

The workshop was divided into two sessions: technical aspects of design and analysis, and application of techniques in the field. Speakers addressing field applications were asked to focus on examples of actual study designs and problems. Expanded reference sections accompany individual summaries and include general, theoretic and field study references. While many of the studies discussed involve hypothesis-testing research, exploratory techniques and situations are also treated. Perhaps less fashionable than hypothesis-testing, exploratory studies are a part of scientific investigation and, as such, can benefit from thoughtful experimental design and careful data analysis.

We gratefully acknowledge the efforts of R. R. Olendorff and J. M. Scott in organizing the workshop, and The Raptor Research Foundation, Inc., for providing the opportunity and funding to make it possible. Reviews by L. David Mech, Gary C. White and Jimmie R. Parrish greatly improved the manuscript. Special thanks to the Condor Research Center for serving as intermediary in the editing process.

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Editor's Note: Pages 125–146 of this issue represent summaries of material presented at the 1985 Telemetry Workshop.

APPLICATIONS AND CONSIDERATIONS FOR WILDLIFE TELEMETRY

MARK R. FULLER

This presentation is a review of radio telemetry; that is, the sending of information over some distance using radio frequencies. The technique is a form of biotelemetry, which also includes laboratory/physiology applications wherein signals can be transmitted from subject to receiver/recorder. Radio telemetry is a research tool. When using telemetry, it is essential to consider how it is to be used to achieve one's objectives and what time and money will be required.

Telemetry can be used by the researcher to accurately locate animals for further observation, to determine home range, habitat use, migration routes, activity patterns, predator-prey relationships, survival, and to locate nests, roosts, etc. Transmitters that gather data on the microclimate of the animal have also been developed. In addition telemetry has been used to obtain physiological data. Examples of many of these uses were presented by Amlaner and Macdonald (1980).

Transmitter attachment techniques are as diverse as the size, shape, weight and application of the transmitters. References at the end of this summary provide an introduction to the general literature on wildlife telemetry techniques, and Kenward's paper (1985) provides a good review of raptor telemetry. Successful attachment techniques are far better documented than failures. Therefore, before trying new methods and equipment, check with researchers experienced with similar techniques and species. To summarize briefly, tail mounts can only be used with comparatively light-weight transmitters and are lost when feathers are molted. Backpack transmitters require suitable harness material; teflon ribbon has been useful on raptors. Glue-on transmitters have not been used often on raptors. Transmitters powered by solar cells are very lightweight and can be used alone or with rechargeable batteries to provide nighttime coverage (Wischusen 1981; Kenward 1987). Solar transmitters are not compatible with attachment techniques that allow birds to preen feathers over the transmitter or with animals inhabiting dense vegetation.

Before beginning a radio telemetry study, biologists should determine how long the animals must

be monitored. Larger (and heavier) batteries provide longer life and stronger radio signals. Consider compromising between time and weight. Make sure that the company supplying your equipment understands your needs and has experience with similar applications. Design engineers usually provide optimistic estimates of transmitter life, based on signal strength and pulses of their products. However, many variables that affect equipment performance on an animal in the field cannot be factored into basic electronics considerations.

Time frame of the study will also determine appropriate attachment techniques. Many harness materials (e.g., teflon) last for months or years. Presently, few attachment methods (e.g., glue, fasteners for harness material) have been developed to reliably detach at pre-determined durations after attachment. However, David Garcelon (Institute for Wildlife Studies, P.O. Box 127, Arcata, CA 95521) has had success developing a drop-off attachment for Bald Eagles (*Haliaeetus leucocephalus*). Tail mounts are useful for studies not extending beyond a molt.

Behavioral and energetic changes in animals carrying radio transmitters have been incompletely documented for a few species and are completely undocumented for many others. In the short term there may be a period of up to several days of reduced activity as the animal adjusts to a harness and transmitter. Over a longer period, brood abandonment, icing and tangling have been documented for a variety of mammals and birds. Some diving ducks will not feed normally with harness attachments (but see QUESTIONS section). Jim Gessaman (UME 53, Utah State University, Logan, UT 84322) and Mark Fuller (Patuxent Wildlife Research Center, USFWS, Laurel, MD 20708) are investigating energetic implications of additional weight and thermal effects of large transmitters (as a heat sink). A recent article by Caccamise and Hedin (1985) deals with bird size and appropriate transmitter weight. In general transmitter weight should be a smaller percentage of body weight for larger birds than for smaller birds. Transmitter weight affects potential maximum velocity, maximum power and endurance. As a result, escape speed, pursuit speed, payload, persistence of

Table 1. Suppliers of telemetry equipment (compiled June 1987).

Advanced Telemetry Systems, Inc. 23859 NE Highway 65 Bethel, MN 55005 (612)434-5040	L.L. Electronics P.O. Box 247 Mahomet, IL 61853 (215)586-2132
Austec Electronics, Ltd. #1006, 11025-82 Ave. Edmonton, Alberta T6G 0T1 CANADA (403)432-1878	Lotek Engineering, Inc. 11 Younge St. S Aurora, Ontario CANADA L4G 1L8 (416)727-0181
AVM Instrument Co., Ltd. 2368 Research Dr. Livermore, CA 94550 (415)449-2286	Microwave Telemetry 610 Chestnut Ave. Towson, MD 21204
Bally Ribbon Mills 23 N. 7th St. Bally, PA 19503 (215)845-2211 (For teflon ribbon harness material)	Midwest Telemetry Judy Montgomery P.O. Box 773 Urbana, IL 61801 (217)367-1904
Beacon Products Co. 360 East 4500 South Salt Lake City, UT 84107 (801)265-1383	Narco Scientific (short range-biomed) 7651 Airport Blvd. P.O. Box 12511 Houston, TX 77017 (713)644-7521
Biotrack Stoborough Croft Grange Rd., Stoborough Wareham, Dorset BH20 5AJ ENGLAND Wareham (09295) 2992	Remote Monitoring Systems P.O. Box 2155 Walla Walla, WA 99362 (509)529-1060
B & R Ingenieurgesellschaft mbH Johann-Schill-Str. 22 7806 March-Buchheim, WEST GERMANY	Scien-O-Tech Consultants, Ltd. Box 14426 NAIROBI or Box 87054 Mambasa, KENYA
Custom Electronics of Urbana, Inc. 2009 Silver Ct. West Urbana, IL 61801 (217)344-3460	Telemetry Systems, Inc. 11065 N. Lake View Dr. P.O. Box 187 Mequon, WI 53092 Owner—Owen Royce (414)241-8335
Custom Telemetry and Consulting 185 Longview Dr. Athens, GA 30605 (404)548-1024	Telonics 932 Impala Ave. Mesa, AZ 85204-6699 Owner—Dave Beaty (602)892-4444
Holohil Systems Ltd. RR 2 Woodlawn, Ontario CANADA K0A 3M0 (613)832-3649	Wildlife Materials, Inc. R.R. 1 Carbondale, IL 62901 Wildlife Consultant—R. E. Hawkins (618)549-6330
J. Stuart Enterprises P.O. Box 310 Grass Valley, CA 95945	

fat reserves, flight distances and stopover times can be affected. Added drag affects aerodynamic performance and can alter a bird's center of gravity. C. J. Pennycuik (Department of Biology, University of Florida, Coral Gables, FL 33124) has suggested tests for transmitter effects on various flight behaviors and mechanics, and Pennycuik and Fuller are studying some of these aspects. Given that little is known of the impacts of transmitters on animals, it might be desirable to recapture test subjects and remove transmitters, which is often difficult and time consuming.

A little-known fact about radio telemetry is that one needs a license from the Federal Communications Commission (FCC) to conduct telemetry studies. There are restrictions on frequency, power output, numbers of transmitters per unit area, etc. Kolz (1983) has published an informative article on the subject, giving pertinent restrictions. The U.S. Fish and Wildlife Service Bird Banding Laboratory, Laurel, MD 20708, provides brief information on regulations, and a list of companies that manufacture wildlife telemetry equipment (Table 1).

QUESTIONS

William Cochran stated that Judy Montgomery (Midwest Telemetry, see Table 1) has designed a neck collar transmitter attachment that appears not to interfere with the normal feeding activity of diving ducks.

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EXPERIMENTAL DESIGN OF TELEMETRY PROJECTS

KEN POLLOCK

In its short life radio telemetry has progressed from a "fascination" stage characterized by small studies of poor design based on unrealistic expectation to a stage of more sober reassessment. At present we are seeing studies of possible problems involved with telemetry, composite studies which test telemetry against other techniques and a general atmosphere of more cautious expectation. In the future we can hope to work with telemetry as a thoroughly researched tool with known strengths and weaknesses for which accompanying texts and sound analysis techniques are widely available.

Telemetry studies are generally costly and therefore tend to be multipurpose so that many questions can be addressed from one data set. This in turn leads to tradeoffs among sample size, accuracy of location, frequency of location, etc.

In developing telemetry studies four points should be addressed to help ensure that the results are meaningful and may be analyzed as intended.

- 1) **Define the experimental unit.** Some studies will seek to analyze bird-days of observation, others will be concerned simply with the number of birds. The former contains a degree of ambiguity as one bird followed for 20 d, 20 birds followed for one d or five birds followed for four d will all yield 20 bird-days, although there are important differences in conclusions made from each data set. Defining the experimental unit as one bird avoids ambiguity.
- 2) **Attempt to insure that study animals are randomly selected from the population to which you wish to make inferences.** Basically, the trapping technique should be unbiased as to age, sex, size, habitat type, etc., within the chosen population.
- 3) **Try to estimate the replication the study will require** (see pilot study in QUESTIONS).
- 4) **Determine what, if any, type of stratification you will employ** (see pilot study in QUESTIONS).

Inappropriate or insufficient experimental designs can be difficult to detect or remedy, but a number of them can be found in the literature. Mortality studies are often characterized by inadequate sample size and questionable experimental units. Custom-

arily, survival on any given day is assumed to be independent of survival on any other day, although this assumption is not tested. Similarly, home-range studies also suffer from inadequate sample sizes, both of animals and of animal-locations. If a study is designed to produce inferences for all age/sex classes, it must have adequate representation of each of those classes. Home-range estimates are dependent on the time frame of the study and on sampling intensity. If either time frame or sampling intensity is increased, estimated home-range size will also increase. In general researchers seem to have an insufficient understanding of the concept of home-range and of how the picture of home-range changes depending on the study framework. Hopefully, continued work on this problem will lead to a better definition of home-range.

As a brief experiment in study design tradeoffs, let us look first at a mortality study designed to quantify overwintering survival. In order to cover all age/sex classes you probably need 50-100 animals even to consider beginning the study. The good news is that you probably only need to locate the animals once each day, or with long-lived species perhaps once each week. Even with the decreased observation intensity, such a study may be impractical for many species.

Now let us look at an activity study designed to quantify activity patterns between and within days. Initially we have several options, three of which are listed below.

Design 1: one bird followed for 40 d with 16 locations/d.

Design 2: 40 birds followed for one d each with 16 locations/d.

Design 3: 10 birds followed for eight d each with 16 locations/d.

The first two designs are extreme and inappropriate. Design 1 looks only at one bird, so there will be no way to estimate the variance of activity patterns among birds. If you study an abnormal bird, you could generate an array of misleading information, and if you study a normal bird you will still have no way of estimating the range of normal behavior.

Design 2 looks at each bird for only one day, so there will be no way to estimate the variance of activity patterns between days. You can estimate the variance between birds and between days (assuming you did not follow all 40 on the same day) together, but you cannot estimate the effect of only bird-to-bird differences or of only day-to-day differences. Design 3 is one possible compromise: an intermediate number of birds, days and locations which would permit estimates of all variances of interest. However, optimal balance among birds, days and locations is complex and can only be determined using a good pilot study.

Costs will invariably affect study design, as will time needed to switch between animals and many other nonstatistical concerns. So even for a fairly straightforward question, such as the activity pattern experiment above, determining the best design can be difficult.

As the previous examples illustrate, some study designs will be incompatible with each other. We could not run a mortality study and an activity study simultaneously without going to very great expense: one requires many animals with few observations/animal/time, the other requires few animals but more observations/animal/time. Two additional problems occur with activity studies. Missing values can require increased complexity in the analysis, so it is best to develop a regular sampling framework which is always achievable. Secondly, the interdependence of locations which are close in time is a statistical problem only now being addressed. Many home-range analyses assume that all animal locations are independent of each other, although many study designs produce dependent locations. Pantula and Pollock (1985) presented a time-series approach to this problem.

One plea here from the statisticians: please do not overvalue lots of data on few animals. Many times a good design will be too costly to achieve and the biologist will continue anyway in the hopes of gaining at least some useful information. While this is certainly not a waste of time, writers should acknowledge limitations of their results and avoid making far-reaching statements from scanty data. To date statisticians have been only occasionally involved in telemetry analyses. Telemetry lends itself to tailored analysis techniques due to its specific problems and approaches. More statisticians should become involved so that analyses can become effective and available.

QUESTIONS

Re continuous monitoring of animals vs. distinct locations at known time intervals: in general too much data is generated from too few animals. Often no additional information is gained by much additional observation. However, in specific cases it may certainly be appropriate to monitor continuously, as when the exact duration of a given activity/movement is of interest.

Re the effect on mortality estimates of bird/day units vs. bird units: estimates of mortality made using bird/day units will be unbiased, but the estimate of the variance will be too small.

Re the gathering of lots of information/bird: if the goal is to describe the activity of one or a few animals without making inference to a population, then small numbers of animals are not problematic. But if your goal is statistical inference from a sample to a population, then fewer data on more animals is better. Of course lots of data on many animals is best of all but seldom practical.

Re pilot studies: the problem of adequate sample size is best addressed by a good pilot study which can provide an estimate of variability of variables of interest. Pilot studies also permit estimates of cost, time, personnel needs, etc., and can save time and money in the final study.

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ANALYSIS OF SURVIVAL DATA FROM TELEMETRY PROJECTS

CHRISTINE M. BUNCK

Telemetry is an increasingly popular method for studying animal movements and habitat use. Additionally, telemetry provides a means for studying survival and causes of mortality. In this paper I will be describing some statistical techniques which can provide valid estimates of survival rates based on data from telemetry studies.

Two basic study schemes are used to observe survival time. In the first, observations on all animals begin at the same time. In some instances time origin will correspond to some biologically meaningful date such as average fledging date, but often time origin is simply the beginning of the study. In practice it is often impossible to mark all animals in one day, but the period of capturing and marking should be as short as possible. In the second study scheme animals enter the study periodically. For wildlife studies this scheme will probably be more common than the first.

The techniques I will describe can be applied to lifetime data as recorded under the first scheme. Some, but not all, of these techniques generalize to the second scheme. The following five assumptions apply:

Assumption 1) The sample is representative of the population to be studied; requires that trapping techniques result in random captures from the population without age bias, sex bias, etc.

Assumption 2) Survival is not influenced by radio-marking; if not, study will give a biased estimate of population survival rate.

Assumption 3) The fate of each animal studied is independent of the fate of any other animal studied; would not be the case for nestlings. If a predator finds the nest, all or most of the nestlings will probably die. Similarly, the fate of a young animal is closely linked to its mother's fate in many instances.

Assumption 4) Censoring [censoring occurs when an animal's fate becomes unknown (e.g., when its transmitter fails)] is independent of fate; a censored animal is just as likely to be alive as dead.

Assumption 5) Exact time of death is known. Simulation studies have shown that this assumption can be relaxed (Heisey and Fuller 1985).

Assumptions 1-3 are also required for band recovery models. Assumptions 4 and 5 are unique to techniques for the analysis of survival data.

I have classified techniques as discrete or continuous models. All equations have been eliminated from this summary, but can be found in the literature cited. Discrete models are those in which survival is described as an outcome observed after some unit of time, such as a day or a week. One widely used discrete model uses an approach originally proposed by Mayfield (1961) for the study of nest success. Mayfield's model is distinguished from other discrete models by two assumptions:

Assumption 1) The probability of surviving a period is the same throughout the study (e.g., chance of surviving in any day/week is the same as in any other day/week).

Assumption 2) Each time unit (trial) is independent of the next trial.

Estimation of survival rate over a period of days and testing procedures have been described in papers by Johnson (1979), Hensler and Nichols (1981) and Bart and Robson (1982) concerning study of nesting success but results can be applied to data from telemetry studies with application to both single-origin and staggered-entry study schemes.

I'd like to mention three other papers that employ discrete models for data analysis from telemetry studies. Trent and Rongstad (1974) were among the first to use a Mayfield-type approach to obtain survival estimates from telemetry data. White (1983) proposed a multinomial model to estimate survival rates from telemetry data and obtained estimates and tested survival rates. Heisey and Fuller (1985) refined the Mayfield approach to permit calculation of survival rates which are not constant over long periods (for many species, survival rates vary between seasons, etc.). Intervals were set in which survival rates were nearly constant, Mayfield estimates were computed for each interval and the product of these estimates used for the entire period. Programs by White and by Heisey and Fuller are available from them.

Continuous models treat survival time as a con-

Table 2. Nonparametric tests^a for comparison of survival times.

TEST AND CONDITIONS
No censoring (fate of all animals is known)
Mann-Whitney U
Wilcoxon Rank Sum
Kruskal-Wallis
Savage
Logrank
Censoring (some fates unknown)
Gehan
Peto-Peto
Peto-Pentice
Mantel-Haenszel
Logrank

^a For further information on individual tests, see Lee, E. T., Statistical methods for survival data analysis. Lifetime Learning Publ., Belmont, CA, 1980.

tinuous measure using two major approaches. A parametric approach requires that distribution of survival time values be completely specified. A non-parametric approach does not make assumptions about form of survival time distribution.

For parametric approaches one of three functions must be precisely defined.

Table 3. Contacts for computer software programs.

PROGRAM	CONTACT
BMDP^a	BMDP Statistical Software 1964 Westwood Blvd. Suite 202 Los Angeles, CA 90025
GLIM^b	Numerical Algorithms Group 7 Banbury Road Oxford OX2 6NN, Britain
SAS	SAS Institute, Inc. Box 8000 Cary, NC 27511
SURVREG^c	Dr. Douglas B. Clarkson IMSL Inc. 2500 Citywest Blvd. Houston, TX 77042-3020 (713)782-6060

^a Biomedical Computer Package.
^b General Linear Interactive Modelling.
^c Survival Analysis with Regression.

Function 1) The probability density function which describes the expected occurrence of survival time values.

Function 2) Survival function which is the probability of surviving longer than given periods of time.

Function 3) Hazard function defines chance of dying in the next small interval, given that the bird is alive at the beginning of the interval.

Given one of these functions, the others can be derived.

Exponential distribution is commonly used in survival analysis and assumes that the chance of dying does not change with age or time—essentially the Mayfield approach with a continuous model. The approach is straightforward for studies with no censored animals and a defined time of origin. When censoring occurs, iterative (usually computer-calculated) procedures are required to obtain estimates, and staggered entries introduce further complexities into the estimation and computation process. Non-parametric approaches are applied when one is unwilling to specify a model for survival time, but it is still desirable to treat survival time as a continuous variable.

Kaplan-Meier (Lee 1980), or product-limit, estimate provides a method for estimating survival function—probability a bird survives longer than some given time. Censored animals and staggered entry schemes are permissible with this approach. The Kaplan-Meier estimate can be used descriptively to evaluate the assumption of independence between censoring and fate of the bird by displaying worst-case/best-case scenarios. Estimates can also be used to describe cause-specific mortality. Table 2 lists additional nonparametric tests based on linear rank statistics. In the literature there are several variations for each. All can be applied to single-origin schemes, but only the logrank test generalizes to the staggered entry scheme.

Programs for parametric and nonparametric approaches can be found in statistical packages BMDP (Biomedical Computer Programs) (Dixon 1983) and SAS (supplemental library; SAS Institute 1985) and in SURVREG (Survival Analysis with Regression) (Clarkson and Preston 1983). See Table 3 for contacts.

Finally, the Cox proportional hazards model (Cox and Oates 1984) provides a semi-nonparametric continuous approach which assesses the relationship be-

tween survival time and related variables such as age, sex, weight at capture and condition at capture. Cox models can be fit using BMDP, a procedure in the supplemental library of SAS, and GLIM (General Linear Interactive Modelling) (Baker and Nelder 1978). See Table 3 for contacts.

For the study of survival with telemetry techniques, enough locations should be obtained to avoid censoring and obtained often enough to avoid misclassifying a death when causes of death are being studied. For some discrete models, locations should be obtained at equal intervals.

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BASIC TECHNIQUES FOR ANALYZING MOVEMENT AND HOME-RANGE DATA

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Circular Statistics for Movement, Migration and Dispersal Data. Data collected using radio telemetry may comprise daily flight lines of a migrating bird, overall dispersal lines of a cohort of juvenile animals from natal locations to their locations at some later time or some other collection of line segments. Important qualities of data are direction and distance of movement, which are represented as vectors. Often, one may wish to analyze vector length separately from vector direction. Movement distance may be related to age, sex, weight, weather, etc., while direction may be related to guiding lines, prevailing winds, latitude, etc. (Heintzelman 1975). Distance (length) can be analyzed using standard statistical techniques. Direction, however, often cannot. Consider two dispersing individuals, one on a heading of 359° , the other on a heading of 1° . Intuitively, the average is 0° (i.e., due north), but standard math tells us the average is 180° . Likewise consider 0° , 120° and 240° , which divide a circle into thirds. Their average is 120° , which is nonsensical. Further, if we call those same lines 120° , 240° and 360° , the average becomes 240° , although we are still analyzing the same lines. These anomalies are characteristic of attempts to analyze data for which no true zero point exists.

Circular statistics are designed to permit analysis of angular data. One can calculate an average angle of dispersal separately from average distance, or average angle of a day's migration path separately from average daily travel. Analogs to familiar *t*-Test, Chi-square Test and many other parametric and non-parametric tests exist which permit one to test for differences in direction of two populations (e.g., differences in dispersal direction of two cohorts or differences between migration paths and available guiding lines). Circular statistics can also be used to determine whether path directions are randomly distributed or show a significant tendency toward a given direction. The reference section lists some excellent texts dealing with circular statistics.

Techniques for Analyzing Home-range Data. Home range and core area sizes are frequently cited by resource managers as a quantitative basis for resource protection. Several methods can be used to

calculate home ranges or land-use patterns, and no single figure can accurately reflect an animal's use of its surroundings. I will review some of the commoner analyses, then focus on two recent computer-generated models of home-range/use patterns. I will not address the problems associated with collecting accurate location data with telemetry (see Grainger Hunt's summary for references).

Home-range data usually consist of a series of points collected over some period, hopefully at regular intervals. The simplest method of representing observations is to plot them on a map, which may be sufficient for many uses, but often you will need or want to estimate area used by study subjects or to indicate high-use or core areas. We will assume for the following discussion that in addition to the map, you have devised some sort of a grid coordinate system so that each observation point can be indicated by a pair of X,Y values.

For many years the standard method of estimating size of home range was the minimum convex polygon, constructed by connecting the outermost observation points. The technique tends to be overly generous including many unused areas and is sample size dependent but requires no computers.

A quick approach to finding core areas is simply to locate the area of the map which contains the highest density of observations and perhaps a nest, den or roost tree as well. However, the urge to generate numbers may drive you to attempt an "average" location by averaging the X and Y values of your observations, often producing a location that the animal never uses. For example "average" location of a creature which hunts around the edge of a pond is very apt to be in the pond. While this example is extreme, it points to a problem with straight averages—the animal has no knowledge of your X,Y grid and no reason to order its movements around the average. Despite this fact, one widely-used technique of home-range analysis relies on the arithmetic mean location to construct a series of probability ellipses or circles. A 95% probability ellipse would be assumed to enclose 95% of the range. Just as animals are generally ignorant of arithmetic means, they are not generally disposed to move in

Table 4. Home-range computer programs.

FEA-TURES	DETAILS		
Source	Dr. Edward O. Garton Fish and Wildlife Dept. Univ. of Idaho Moscow, Idaho 83843	Ms. Laura Beery Conservation and Research Center Nat'l Zoological Park Smithsonian Institution Front Royal, VA 22630	Ms. Blair Jones Dept. of Fisheries and Wildlife Science Virginia Polytechnic Institute Blacksburg, VA 24061
Use	Home Range: mainframe FORTRAN, IV or 77, Calcomp plotter	McPAAL: TURBO PASCAL for IBM-PC, -XT, compatibles, Epson or IBM graphics printers, in future for Summagraphics and H P plot- ters	TELEM: for IBM 370, IBM- PC, -AT. Tektronix and H P plotters
Graphics	Polygons, ellipses, weighted ellipses, har- monic mean, Fourier transforms, tests for distribution types, tests for independence of ob- servations	Convex, concave polygons, ellipses, harmonic mean Fourier transform	Convex, concave polygons, polygms, ellipses
Cost	\$250.00 includes updates	\$15.00 includes updates	\$15.00

ellipses or circles; thus, we will dispense with further discussions of probability ellipses on the grounds that they are unrealistic and that better techniques exist.

To return to the problem of centers and cores there are many different measures of the “center” of a distribution of points (e.g., arithmetic mean, geometric mean, mode, median, harmonic mean, etc.) each with different properties. The harmonic mean is the basis for one of the newer home-range techniques. A harmonic mean, which can be defined for any point on a map, not just the center, is basically a measure of the average distance from a given point to all observation points. A point that is near the center of a dense cluster of observations will have a small average distance to observations, while a point on the perimeter will have a larger average distance and hence a larger harmonic mean.

The point with the smallest harmonic mean is the point that is as close as possible to as many observations as possible and is called the harmonic mean center. Note the harmonic mean center must always occur in an area of high use, never in an area the animal never uses, since the harmonic mean center is defined by animal locations. Since you can measure a harmonic mean anywhere on a map, you can calculate a harmonic mean for all intersections of an X,Y grid (or every quadrant of each square, or whatever) and use the values to create isolines (contours) (Dixon and Chapman 1980).

Points that are the same average distance from observations will have the same harmonic mean; peaks will occur at high-use areas and valleys in low-use areas. By plotting isolines over observation points, one can calculate area of the isoline that encloses 50% of locations, which can be considered an estimate of 50% use-area. Similarly a 95% or 99% isoline can be considered an estimate of home-range. One assumption about mathematical properties of data has been made: each observation is independent of all others. The independence assumption is a major problem that we are ignoring for lack of time (but see the summary of Ken Pollock’s discussion and references hereafter). The animal defines the shape of the map and we have made no assumptions about shape or distribution of home-range.

Anderson (1982) takes a different approach to the home-range problem. Think of the X,Y grid overlaying the map as a checkerboard. Every time an observation occurs in a square, put a checker in that square. Soon, we have a stacked-up checkerboard with big stacks in core areas and no checkers where the animal has not been seen. We have created a three-dimensional histogram, with frequency of occurrence graphed as the third dimension. A measure of use can be obtained by looking at volume of checkers over land area of interest. We could leave it here, at the checker stage, but the results are rough, and do not permit inferences about presence of travel

ridors (which are notoriously difficult for obtaining data) between high-use areas, etc. Anderson's (1982) technique uses the method of Fourier transforms to smooth out the peaks and valleys a bit, put saddles between close peaks and valleys between distant peaks. By looking at volume under the landscape, one can define use areas by the isoline that encloses a given percentage of the volume—perhaps 10% use area for cores or 90% use area for an estimate of total home-range size.

My summaries of home-range techniques are meant to be brief introductions and mention none of the shortcomings or underlying mathematics. I feel the techniques are promising and worthy of attention, but not perfect; researchers should read the supporting papers thoroughly before employing programs. Both Dixon and Chapman's (1980) harmonic mean technique and Anderson's (1982) Fourier technique are published with references for programs to generate area figures. However, several individuals and institutions have computer packages that execute these and other techniques of home-range analysis. Table 4 lists some available packages, addresses and abilities.

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DETECTING AND DESCRIBING THE STRUCTURE OF AN ANIMAL'S HOME RANGE

PAUL H. GEISSLER AND MARK R. FULLER

This presentation is an oral version of Geissler and Fuller (1985). We suggest use of casement displays (Chambers et al. 1983) to represent animal use of home range over daily and seasonal time scales. In addition we suggest a clustering technique for use in detecting patterns in structure of home range.

Casement display is a graphical technique that permits more than two dimensions to be displayed in two dimensions; we use five dimensions (east, north, time of day, season of year and frequency). While casement displays have not been widely used in home-range studies, they permit faster and clearer understanding of temporal and spatial patterns of home-range use than simpler mapping techniques currently in use. Casement displays require some familiarity before use becomes easy; some helpful references are listed at the end.

Clustering techniques provide a quantitative basis for detecting patterns within a home range. Previous techniques have allowed quantitative assessment only of home range spatial patterns. The combination of clustering techniques with casement displays permits quantitative investigation of temporal as well as spatial patterns.

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TELEMETRY IN STUDIES OF PREDATION, DISPERSAL AND DEMOGRAPHY

ROBERT KENWARD

General structure of a radio-telemetry study can be divided into four stages:

- Stage 1**—acquiring equipment
- Stage 2**—capturing and marking animals
- Stage 3**—developing field techniques
- Stage 4**—analysis

Each stage should be considered before starting a project, as each affects the others. Many projects fail from lack of adequate field techniques. Reliable equipment and transmitter attachment are essential (see Mark Fuller's summary in these proceedings). Care taken in selecting equipment and in hiring personnel will yield better data. Personnel comfort, especially at night or under extreme conditions, improves resulting data and lengthens lifespan of field workers. Be sure you can capture enough of your animals and that you can follow them adequately. A good road net or dependable aircraft to decrease travel time is necessary when following many animals. A large travel budget will also be needed. A pilot study is very helpful, especially to estimate costs: it is painfully easy to underestimate travel costs, forcing curtailment or premature termination of the study when funds run out.

The role of experience in telemetry studies cannot be overestimated. It is obvious that new personnel must be given time to learn to track animals, but it is less obvious that tracking large numbers of animals for dispersal and survival studies requires different skills from those used in studies of individual behavior or predation. Telemetry studies tend to evolve as they continue, and there must be time for this evolution. Data collection is seldom satisfactory until the second or third study season. Flexibility of study design is advisable as you gain experience in field techniques and refine your study questions. Analyze your data as you progress, and discuss results, so that changes in data gathering can be made as new ideas and questions arise. The final ingredient, luck, is unfortunately stochastic and difficult to obtain on short notice. But it does help.

Predation Studies. Predator-prey interactions can be studied by marking either the predator or the prey. If behavior and predation of one predator is

of interest, or if many fresh kills must be examined (e.g., for selection effects), marking the predator is indicated. If a guild of predators is of interest then it may be best to mark prey. Recording each kill adequately will be more difficult, and kills may be attributed to a scavenger rather than the real predator.

In studying Goshawk (*Accipiter gentilis*) predation on Wood Pigeons (*Columba palumbus*) it was easiest to mark the Goshawks. Following individual hawks gave data on time spent in various habitats, detailed movement along search paths, types of prey taken and kill rate. Analyzing fresh kills for selection effects showed that Goshawks tended to take pigeons with below average weight, except when prey were taken completely by surprise (Kenward 1976).

After discovering that Goshawks remained for long periods at or near large kills, and learning radio signal cues which indicated a kill, several hawks could be monitored concurrently when studying predation on pheasants (*Phasianus colchicus*) in Sweden; most kills of 250 g or larger could be recorded by checking each hawk at one hr intervals. Fewer behavioral data were obtained than when following individual hawks but larger samples of kills and of predation rates were obtained from different hawks. Radio transmitters were also used to estimate hawk density, since the number of transmitted hawks in the area was known, and each hawk seen could be checked for the presence of a radio much more easily than for a visual marker. Combining average kill rates with hawk numbers gave an estimate of predation impact on censused Pheasant populations in several different areas. Diet differences between hawk sexes, and differential prey selection were also studied, most recently with the aid of a radio tag that indicates when a hawk is feeding (Kenward et al. 1981a,b.).

Sociality and Range Use. When recording ranges to estimate habitat use or sociality, minimizing number of fixes required to estimate range size or structure saves much work. If range size is plotted after each consecutive fix for a number of individuals, the area will first show a rapid observation-based increase as the animal is recorded throughout its nor-

mal range. A plot then reaches "sampling saturation," after which recorded range size increases represent continuing small increases in area covered by an individual animal. For grid-cell-based analyses it often takes 200–300 fixes to reach sampling saturation, but studies of three species [Goshawk, Badger (*Meles meles*) and Grey Squirrel (*Sciurus carolinensis*)] have shown saturation for outline ranges (convex polygons) in 30–40 fixes.

Convex polygon areas can be dramatically increased by occasional excursions outside normal core areas. Nonparametric clustering or isoline techniques give a better fit to fixes and make fewer assumptions about spatial distribution than earlier bivariate parametric techniques for estimating probabilistic core areas (e.g., probability circles and ellipses) (see Vicky Meretsky's summary in these proceedings). Core areas can be found by inspecting for a drop in variance coefficient as size decreases along a multi-range utilization distribution; the core includes percentage of fixes which give greater similarity between individual ranges than at larger range sizes.

A sampling regime of three daytime locations plus a roost gives saturation in 10 d for Goshawk maximum convex polygon winter ranges. Contrary to popular opinion, hawks showed little territoriality in winter and gathered with their core areas overlapping at Pheasant farms and other sites with local prey abundance.

Dispersal and Demography. For dispersal and mortality studies, it is essential that transmitters are reliable and do not adversely affect their carriers. After five years of predation studies, Goshawk transmitters had evolved to 1500 mA Li/CuO₂ cells powering single-stage transmitters for 9–12 mo. Tail-mounted tags gave 3–5 km working ranges across flat ground and 10–20 km from high vantage points or aircraft. Recapture rates and weights had been similar between radio-tagged and banded birds (Kenward 1978). Unfortunately, tags could not be tail-mounted on nestlings. Nestlings were equipped with leg-tags and caught 10–20 d post-fledging for tail-tagging, all of which involved development of satisfactory leg tags (which were very prone to antenna breakage) and capture techniques near the nest (Kenward 1985).

My study was done on the 30 000 km² Baltic island of Gotland, which has little emigration or immigration of hawks. Location and survival of 30 juvenile hawks and 20–30 adults tagged each year were

checked mainly at night, because live hawks were then in trees and thus unlikely to be overlooked due to poor signals while feeding on the ground. When several hawks had been lost, the island was searched from the air.

Dispersal date was linked to hawk sex and local food abundance. Hawks tended to remain the least time around nests where and when food was scarce, especially the males, but remained longer at such nests than elsewhere when artificially fed. Dispersing juveniles quite frequently parasitized other fledged broods, especially in prey-rich areas and in years when prey elsewhere was scarce. Mortality was surprisingly low the first autumn, and much less than suggested by banding studies, with a peak of juvenile and adult mortality at the end of winter. Movements have been linked to local abundance of rabbits, an important prey on the island (Kenward, Marestrom and Karlbom, in prep.).

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TELEMETRY TECHNIQUES FOR THE STUDY OF RAPTOR MIGRATION

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Radio telemetry makes it possible to observe migrant raptors in some detail over distance and time intervals. Such observations yield inferences stronger than those generated from fleeting glimpses of passing migrants or lines connecting banding and recovery sites.

Most studies that use telemetry are conducted in areas much smaller than those over which birds range during migration. Methods for such area-related studies are applicable to studies of migrants wherever migrants linger [see Holthuijzen and Oosterhuis (1985), or Hunt's summary herein]. Kenward's comments concerning planning, equipment, personnel, luck, etc., are applicable to serious studies that employ telemetry, including the study of raptor migration. I will restrict my discussion to the use of telemetry in the study of long-distance migrants.

One approach for studying migration is to observe one or a flock of individuals intensively. An airplane facilitates tracking because of its speed and freedom of movement (Gilmer et al. 1981; Mech 1983). Also, at higher altitudes reception is increased to 150 km or more for more powerful transmitters. Unfortunately, air tracking provides little opportunity for visual observation without risk of disturbing the subject. Furthermore, small-scale movements such as short hunting flights and signal variations that signify eating, hunting flight, roosting, climbing, descending, etc., are difficult or impossible to document from an airplane. If a rough plot of a bird's migratory route is all that is desired, a plane is a good choice; if care is taken to be in the air at the right time, anyone familiar with ground tracking can succeed immediately.

Where road networks permit and collection of behavioral data is important, by far the best tracking conveyance is a suitably equipped automobile. Frequent, and often hours-long, periods of visual observation of a migrant raptor as it perches, hunts, feeds, roosts or migrates provide welcome breaks in the monotony of electronic observation. By listening to the signal while watching the subject it is possible to learn to associate signal variations with particular activities. The easiest to associate are the steady signals from a perched or gliding raptor and cyclic

signal fade of a raptor circling in an isolated thermal.

Automobile tracking requires constant route planning and replanning. River crossings and large metropolitan areas can be particularly frustrating. Planned temporary loss of contact is often required in detouring away from the migrant, for instance to cross a river at a bridge. Unplanned loss of contact occurs frequently when the bird comes down. Transmitter range for a soaring raptor is typically 50 km, but in a tree or on the ground range will drop to about 10 km and one km, respectively. Fortunately, search area for a nonflying raptor does not expand with time, and by keeping a running log of azimuth an observer always knows which way to go to close distance. However, routing mistakes, especially when winds aid a migrant, will result in trackers being left hopelessly behind and will require luck or the use of a (rental) airplane to reestablish contact.

An automobile and airplane form an ideal combination for tracking, complementing each other in their strengths and weaknesses. Cost of using both is considerably less than the summed cost of either alone (e.g., air time is not required to monitor a stopped or slowly moving migrant). Another advantage concerns what Kenward calls "lifespan of field workers"; by alternating duties between plane and automobile, observers can extend this lifespan that otherwise (in my experience of living in a vehicle) is about two wks.

A great variety of data may be collected while observing migrants. At the least, one is interested in food sources, daily rate and direction of travel, how the day is budgeted between hunting, perching and migrating, and how all these are affected by weather, habitat and topography or vary with age, sex and geographic region. Unfortunately, the migratory seasons provide time for observations of only a few individuals at most and many seasons may be necessary to acquire a data base that addresses such interests in a statistically sound way.

Small samples can, however, be revealing. For instance, a popular field guide (Robbins et al. 1983) comments that the Peregrine (*Falco peregrinus*) "rarely soars." The first Peregrine I tracked (for two full days in fall 1973) flew a total of 11.9 hr, 82%

of which was interthermal soaring (Cochran 1975). "Rarely" and 82% are quite incompatible yet it is likely that "rarely" was based on a large sample of observations. So, was this bird a freak? A later increase in sample size to 143 hr and 6 birds changed the outcome very little (84% soaring) (Cochran, unpub. data). One is sometimes left wondering which is better, a few high quality observations or a large sample of biased observations?

The slow rate of data acquisition inherent in studying individuals may be avoided in part by focusing on particular questions. For instance, having learned from the study of a few inland migrant Peregrine Falcons that individual migratory flight direction does not vary much from day to day, it is now reasonable to determine directional distribution of inland migrants by one- or partial-day tracks from a trapping area and to make inferences about sources and destinations. Several one-day tracks from a trapping site can be documented from one airplane in a single day; therefore, a large sample can be obtained in one season. Such a study would have little meaning at Assateague Island, MD, where individual Peregrines migrate south for several hundred km along the Atlantic coast before diverging on individual courses. Thus, the value of preliminary studies of individuals is to establish a suitable context within which question-oriented studies involving many birds can be pursued with confidence.

Radio tags may be used as *super bird bands* for the purpose of obtaining occasional or specific locations. For example many tags could be attached at various trapping sites during migration and later located during one or two air searches of winter or summer range. Careful preparations should be made for such studies; transmitters and attachments must be reliable for the required time. Air searches are most efficient when reception range is maximum. Therefore, and because range is very limited when birds are on the ground, a knowledge of time of day and kinds of weather favoring perched and soaring behavior is of great value in planning air searches. Cost effectiveness of such studies improves remarkably for large numbers of tags and can be enhanced by planning supplementary studies such as enroute

tracking of a few birds, more intensive study of some individuals after relocation or gathering specific data on environs of the whole sample.

Fuller (1985) used a satellite to locate a Bald Eagle (*Haliaeetus leucocephalus*) over a six month period. The present limitation of satellite use, solely the result of having to use satellites designed for other missions, is that 100 g radio packages must be used, 10–100 times heavier than conventional transmitters for birds.

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RADIO TELEMETRY IN THE STUDY OF RAPTOR HABITAT SELECTION

W. GRAINGER HUNT

Studies of raptor habitat selection using only visual observation must encounter the problem of differential visibility and penetrability among habitat types. The chief virtue of radio telemetry in habitat studies is elimination of bias of detectability differences since a radio-tagged bird is equally detectable in all habitats. Telemetry also permits night observations which are generally impossible with other techniques.

In each of three studies I will discuss, basic techniques are the same: tag as many birds as feasible in order to approach a good sample size (see comments in Pollock's summary), use a study area large enough to accommodate the movements of all tagged birds and determine position as closely as possible, generally once or twice/d if possible. A powerful transmitter is invaluable in such studies, particularly if study animals are not predictable in their locations. Habitat must be mapped, or a previously completed map must be obtained. To explain observed preferences, raptor activity in favored habitat(s) is observed visually and aided by telemetry.

There are two basic means of acquiring habitat data. Frequent surveys designed to locate all individuals provide information for all birds under similar conditions. Following individuals for set periods can give more detailed information but introduces variability caused by different conditions during the observation periods. Both methods are useful, and in most cases, study design will suggest one over the other.

The standard method used to determine habitat preference is to calculate amount of time or number of occurrences of birds in each habitat type compared to availability of each habitat type. Habitat availability is measured by calculating total area of each type in the study area. Along a river or other linear habitat, total linear distance can be used rather than area. A Chi-square test or rank correlation test can be used to determine if raptors use habitat types in a different proportion to actual areas available (i.e., if raptor presence is distributed nonrandomly among habitat types). Several recent publications concerning the methodological and statistical problems of

availability/preference data are listed at the end of this summary.

Overlays are often used to assign habitat or other values after a location has been made. Location is plotted on the habitat map and habitat type assigned to that observation. In large heterogeneous study areas it is safer to assign a habitat type at time of observation to avoid the possibility of mismapping or slight inaccuracies in assessing location of the bird. Remember that edge is often a meaningful habitat type. When testing for nonrandom use of habitat one must be aware of possible seasonal shifts. Lumping data from different seasons or years may obscure seasonal or yearly preferences. References addressing the problem of accurate location of signals, and effects of habitat on triangulation accuracy are listed following this summary.

Habitat preferences can be demonstrated fairly readily using techniques outlined above. Often habitat preference studies function as pilot studies suggesting what further research is appropriate to determine cause of preference. Prey availability, prey preference, availability of special features (nest sites, necessary microhabitat features) or other factors may need to be measured.

The common result of data collection to explain habitat preference is a welter of data from many variables potentially capable of explaining observed preferences. Multivariate data analyses may not always be necessary. Simple nonparametric correlation and Chi-square analyses often reveal major relationships more cheaply and quickly. Univariate and bivariate tests should always precede and may render more complicated analyses unnecessary. Sound management guidelines and simple relationships are generally more useful than long equations for many variables of which only one or two are significant. The following three examples demonstrate the study of habitat selection using radio telemetry.

Migrating Peregrine Falcons (*Falco peregrinus*) were studied at Padre Island, Texas, on two consecutive winters. Habitat types had been mapped previously and were easily identified from a plane. Twenty-seven female falcons were located 2×/d

(weather permitting). Preferred habitat was different in each year; thus, the pooled sample showed no selection. Yearly rainfall differences accounted for change in habitat preference; prey availability seemed to be the factor most responsible (Hunt et al. 1980b, 1981).

Wintering Bald Eagles (*Haliaeetus leucocephalus*) were studied on the Skagit River in Washington to determine the impact of planned dam construction. Food availability seemed to explain most habitat preference. Studies of salmon (*Salmo* sp.) availability and eagle feeding habits showed the area was at carrying capacity for Bald Eagles, and dam placement would reduce the local population as eagles emigrated into other areas. Possible alternate use areas were determined by following eagles during a period when a flood rendered the previously used area undesirable (Hunt et al. 1980a; Hunt and Johnson 1981).

Bald Eagles were also studied on the Pit River in northern California. Seven subadults showed definite seasonal movement patterns between the Pit River and a large lake to the north. To study use of the Pit River itself, 33 individuals (juveniles, subadults and nesting adults) were tracked from ground and air. River habitat was mapped in 0.1 km sections. Values for prey availability, public use and other variables were assigned to each section. Eagles showed a definite preference for pools (as opposed to riffles, runs and pocket water). Further studies to determine what microhabitat variables affected eagle use of pools were conducted from blinds located near pools. In another part of the study distribution of Bald Eagles along the river proved to be related to prey biomass and prey-size variability along the river (BioSystems Analysis, Inc. and U. Cal. Davis 1985).

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ELECTRORETINOGRAPHIC RESPONSES OF THE GREAT HORNED OWL (*Bubo virginianus*)

STEVEN J. AULT AND EDWIN W. HOUSE

ABSTRACT.—Electroretinograms were recorded from four Great Horned Owls (*Bubo virginianus*). Two procedures, dark adaptation and flicker stimuli, were used to assess the contributions of rod and cone systems to electroretinograms. Recordings obtained after dark adaptation demonstrated scotopic (rod-generated) components. *B*-waves were broad and rounded and had a fairly long latency. When high intensity single-flash stimuli were used, *b*-waves had shorter latencies, and prominent *a*-waves were present, indicative of the addition of photopic (cone-generated) activity. Photopic activity was more clearly demonstrated with flicker ERGs. Scotopic fusion frequency was approximately 16 Hz. Photopic fusion frequencies were in the range of 35–45 Hz. The Great Horned Owl retina functions optimally during low luminance levels at night. However, the presence of a functional photopic system allows this owl to also function in brighter luminances of day.

The avian retina has been described by some as the ultimate in retinal organization (Walls 1942; Polyak 1957). Avian retinæ, as with those of mammals, contain receptors for dim light (rods) and receptors for bright light and colors (cones). In general retinæ of diurnal birds are dominated by cones while nocturnal birds possess retinæ with a large number of rods and few cones (Walls 1942; Duke-Elder 1958). In owls which as a group are typically nocturnal, vision has retained the same importance as for their diurnal relatives. Owl retinæ have been examined histologically (Bornshein and Tansley 1961; Hocking and Mitchell 1961; Oehme 1961; Fite 1973; Yew et al. 1977; Bowmaker and Martin 1978) and found to have high numbers of rods as would be expected for nocturnal animals. However, Fite (1973) and Oehme (1961) stress that in spite of the predominance of rods owl retinæ contain approximately seven to eight percent cones, even in the most nocturnal species. Relative contribution of the cone component to retinal function has not been studied.

A preliminary study (Ault 1984) suggested that the Great Horned Owl retina produced ERGs that were qualitatively similar to those of other nocturnal vertebrates and dominated by scotopic (rod-generated) components, but under appropriate stimulus conditions some photopic (cone-generated) components were also present. However, the sample size of the study ($N = 1$) was too small to reliably evaluate ERG responses of the species. Martin (1982) suggested that eyes of owls and humans function similarly over a wide range of naturally occurring luminance levels as a result of their optics and struc-

ture. If so, then likely the Great Horned Owl ERG, as in the human, should reveal a duplicity of function possessing both scotopic and photopic components. Functional duplicity is also expected in light of the morphological confirmation of both rods and cones within the Great Horned Owl retina (Oehme 1961; Fite 1973). The objectives of this study were to record and quantitatively analyze ERGs from several Great Horned Owls in order to provide insight into the relative contributions of rods and cones to ERG response.

METHODS

Subjects. A total of eight retinæ from four injured and unreleasable Great Horned Owls provided data for this study. Owls were sedated with 10 mg/kg acepromazine maleate (Ayerst Laboratories) administered intramuscularly and anesthetized with 80 mg/kg ketamine HCl (Ketaject®, Bristol Laboratories) administered intramuscularly. Anesthesia generally causes only slight reduction in amplitude of ERG components (Armington 1974). Eyes were examined ophthalmoscopically prior to testing and did not possess any significant ocular lesions. Subjects recovered fully after approximately 24 hr with no apparent after effects.

Apparatus and Procedures. Light source for dark adaptation tests was a Kodak Carousel projector with a 300 watt bulb. Single-flash stimuli were achieved by alternating opaque filters with empty slots in the carousel. Starting with an opaque filter, the carousel was rotated through an empty slot to the next opaque filter producing an intense flash of light of approximately 200 msec duration. Light was channeled through a slide holder and focused onto a 3 mm dia fiber optic light guide which was inserted into a black box containing the anesthetized owl. The light guide was brought to within a few millimeters of the cornea. Care was taken to insure that the light guide was aligned as closely as possible with the optical axis of the eye. Maximum luminance (i.e., intensity or brightness)

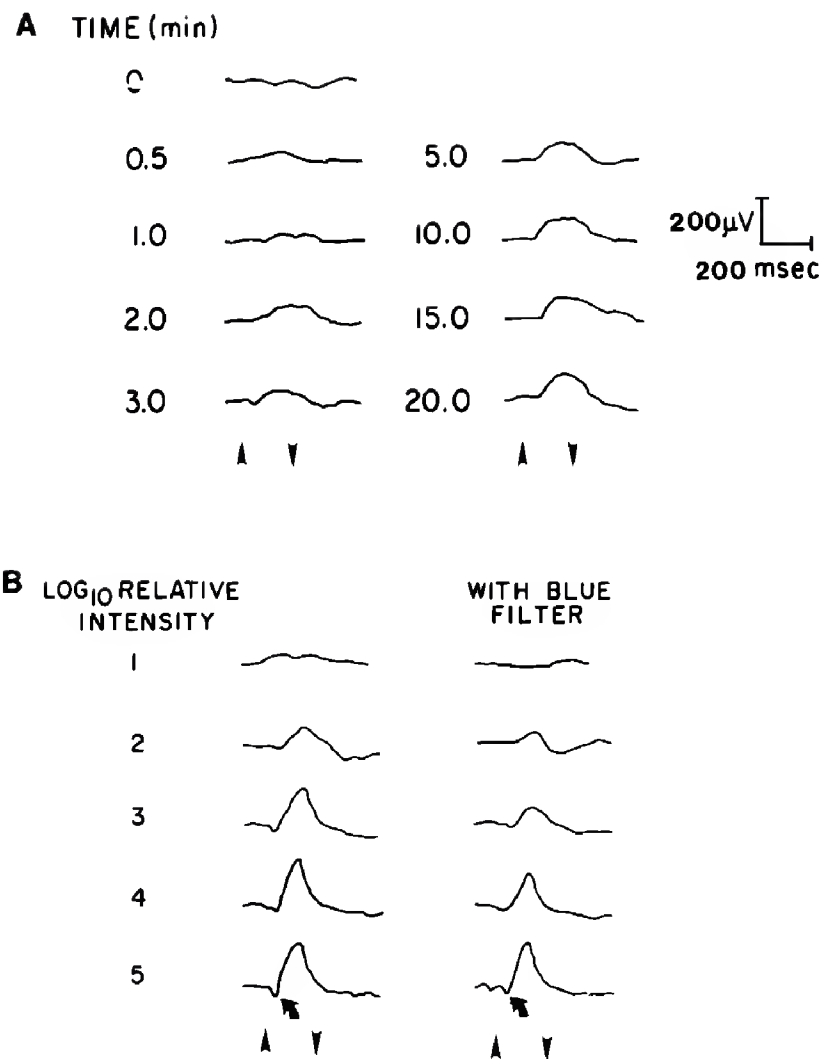


Figure 1. A) Representative Great Horned Owl electroretinograms during dark adaptation. Owl was pre-adapted to constant light of 1.9 cd/cm² for five min. Time indicates minutes after pre-adaptation light was shut off and dark adaptation began. Up arrowhead indicates stimulus on; down arrowhead indicates stimulus off. Stimulus: 1.9 cd/cm² attenuated with a 1 log unit neutral density filter and Wratten #47 blue filter. Note rise in *b*-wave amplitude as time progresses. B) Representative Great Horned Owl electroretinograms produced by single-flash stimuli without (left) and with (right) blue filter. Up and down arrowheads indicate stimulus as above. Relative intensity of five indicates maximum luminance of 1.9 cd/cm². Note *b*-wave increase with increase in intensity. *A*-waves (arrows) appear at high intensities.

of the light source measured by photometer at the cornea was approximately 1.9 cd/cm² and is roughly equivalent to the brightness of a clear sky at noon. Signals from the electrodes were channeled into a Grass 7P1-A preamplifier and tracings were recorded on a Grass Model 7 oscillograph.

Light source for flicker tests was a Grass Model PS33 photic stimulator interfaced with the fiber optic system described above. Maximum luminance measured at the cornea was approximately 0.45 cd/cm². The cornea was desensitized by topical application of Lidocaine HCl (Wyeth Laboratories) and a metal-plated mylar electrode was placed on the cornea (Chase et al. 1976). A needle reference electrode was inserted into skin of the ear canal immediately posterior to the eye and a needle ground electrode was inserted into skin of the wing. Pupil size was monitored throughout the recording session and remained sufficiently dilated to allow a maximum amount of light to enter the eye.

We recorded the responses of the retinæ to both dark adaptation and flicker tests. The dark adaptation test was used to assess scotopic recovery of the retinæ following exposure to bright light. In the dark adaptation test the retina was pre-adapted to constant light of 1.9 cd/cm² for five min. After five min, pre-adaptation light was shut off. Single-flash stimuli attenuated with a 1.0 neutral density filter and a Wratten #47 blue filter were delivered at various intervals to the retina. After owls were fully dark adapted (approximately 45 min), single-flash stimuli of increasing intensities (removal of neutral density filters), both with and without a blue filter, were delivered in succession.

The second test utilized flickering stimuli of various intensities and flicker frequencies to determine cutoff point between scotopic and photopic systems. Maximum luminance measured at the cornea was approximately 0.45 cd/cm². Various neutral density filters, but no color filters, were used in the procedure.

RESULTS

During dark adaptation, mean *b*-wave amplitude increased rapidly from an average of 7.8 μ V at the beginning of dark adaptation to an average of 88.6 μ V at five min into dark adaptation. After the first five min, *b*-wave amplitudes increased at a slower rate and eventually reached an average amplitude of 120.3 μ V at approximately 20 min. Representative dark adaptation ERGs from one owl are shown in Figure 1A. *B*-waves were broad and rounded with

Figure 2. Representative Great Horned Owl flicker electroretinograms at various frequencies. Relative intensity of two indicates maximum luminance of 0.45 cd/cm². Stimulus tracings are shown below each frequency label. Note one-to-one correspondence of ERG response with two Hz stimulus at all intensities (thin arrows). As intensity and/or flicker frequency is increased, one-to-one response is reduced and eventually lost or "fused" (open arrow, for example). Note also one-to-one response at high intensity and high flicker frequency (thick arrow).

LOG₁₀ RELATIVE
INTENSITY

0

1

2

2 Hz

5 Hz

200 μ V
200 msec

0

1

2

10 Hz

15 Hz

0

1

2

20 Hz

25 Hz

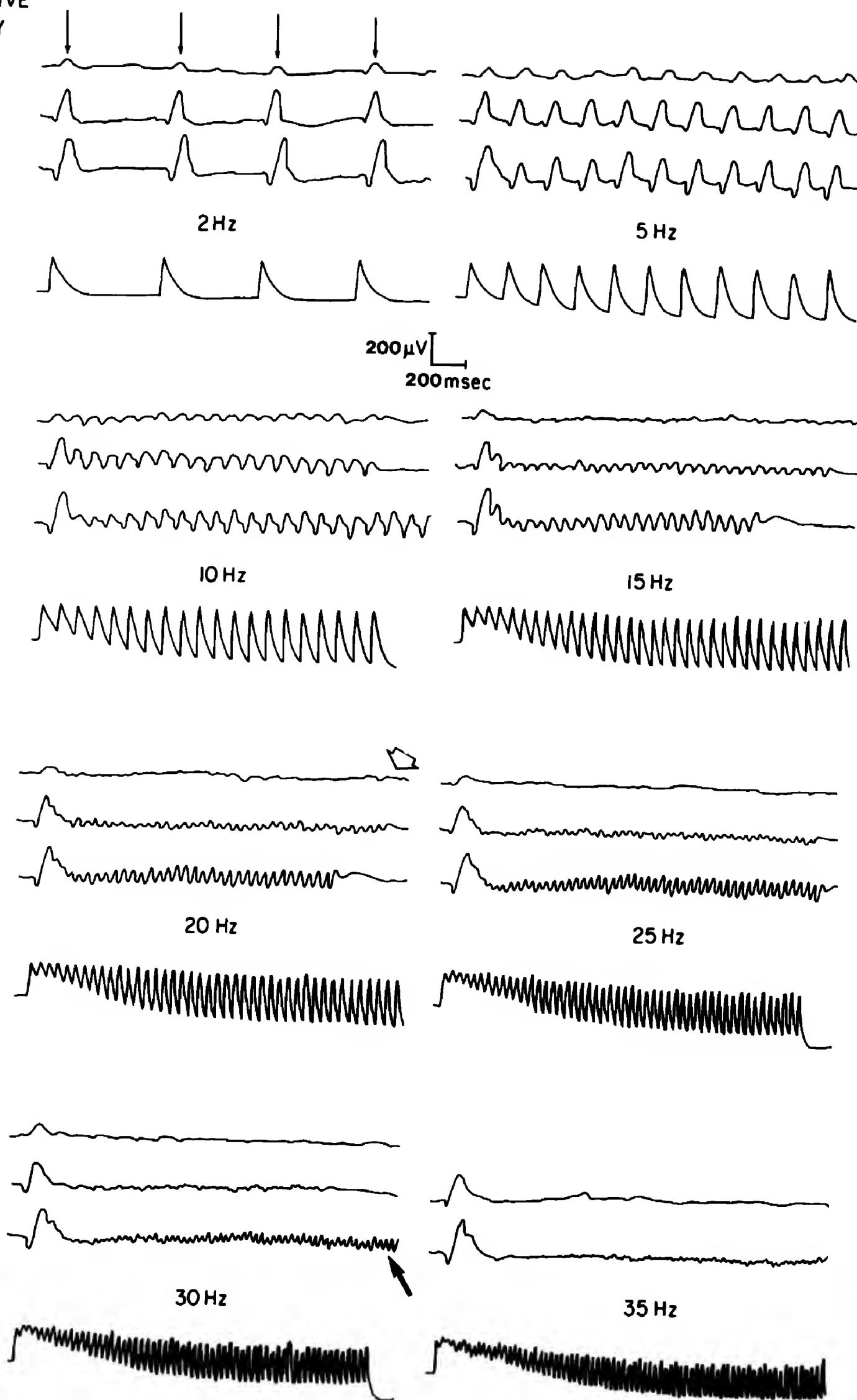
0

1

2

30 Hz

35 Hz



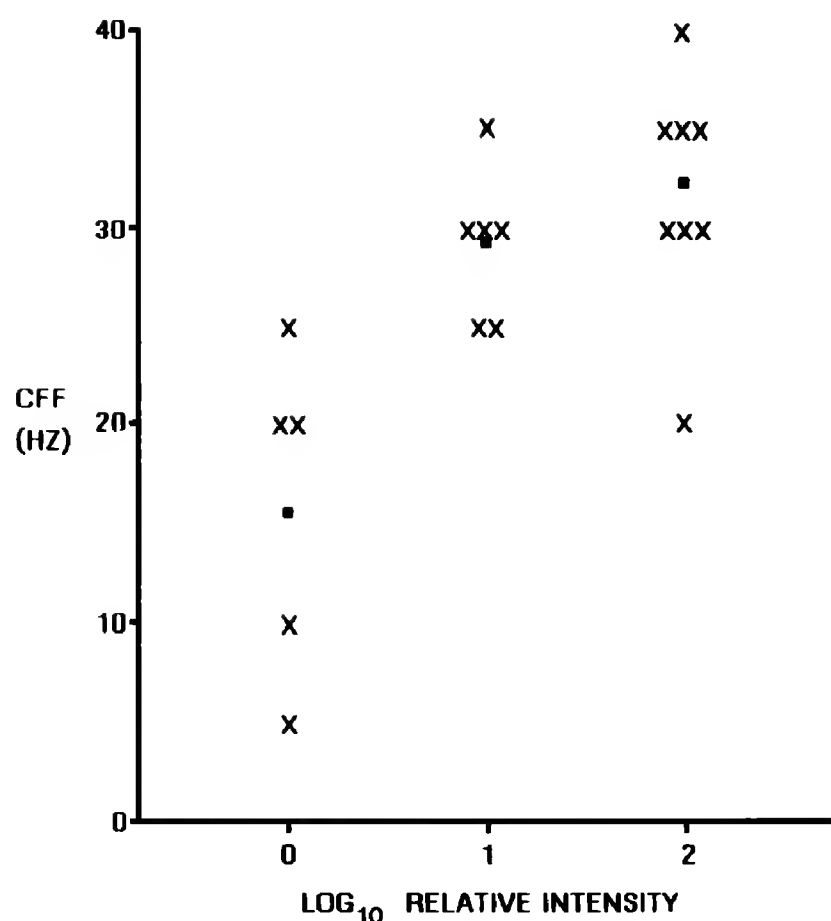


Figure 3. Critical fusion frequencies (CFF) plotted as a function of stimulus intensity. CFF was determined as the frequency at which there was no longer a one-to-one correspondence with the stimulus. Closed squares indicate the average CFF for each stimulus intensity; X indicates individual samples. A significant difference occurs between average CFF obtained at relative intensity of zero and average CFF values for relative intensities of one and two. Average CFF for relative intensities of one and two were not significantly different from each other (Dunnett's *t*-Test; $P < 0.01$ for all between group comparisons). Relative intensity of two represents maximum stimulus luminance of 1.9 cd/cm^2 .

a fairly long latency (average latency = 113.2 msec) and *a*-waves were either very reduced or absent.

Figure 1B shows representative ERGs produced with single-flash stimuli of increasing intensity, both with and without a blue filter, at the end of dark adaptation. In the case without a blue filter *b*-wave amplitudes increased linearly from an average of $77.2 \mu\text{V}$ at lowest stimulus intensity to an average of $305.8 \mu\text{V}$ at highest stimulus intensity. The same pattern was evident when a blue filter was inserted. *B*-wave amplitudes also increased linearly from an average of $63.3 \mu\text{V}$ at lowest stimulus intensity to an average of $254.5 \mu\text{V}$ at highest stimulus intensity. Average *b*-wave latency decreased with increasing

intensity both with and without a blue filter. In the case without a blue filter average latency ranged from 110 msec at lowest stimulus intensity to an average of 71 msec at highest stimulus intensity. In the case where the blue filter was inserted average latency ranged from 155 msec at lowest stimulus intensity to an average of 94 msec at highest stimulus intensity. *A*-waves also became more prominent as stimulus intensity was increased.

Figure 2 shows representative flicker ERGs from one owl. At low light intensities and low flicker frequencies ERG waveforms were evident when responding to stimuli on a one-to-one basis. An eventual loss of the one-to-one response occurred as intensities and flicker frequencies increased. Critical fusion frequencies (CFF) for each stimulus intensity were determined for all owls (Fig. 3). Analysis with Dunnett's *t*-Test showed that there was a significant difference between the average CFF obtained at 0.0 log units intensity ($16.0 \pm 3.7 \text{ S.E.}$) and average CFF values for 1.0 log units intensity ($29.2 \pm 1.5 \text{ S.E.}$) and 2.0 log units intensity ($31.9 \pm 2.1 \text{ S.E.}$). However, average CFF values for 1.0 and 2.0 log units intensity were not significantly different ($P < 0.01$ for all between group comparisons).

Interestingly, the initial flicker ERG waveform changes shape as intensity and frequency are increased. Increase in *b*-wave amplitude and decrease in *b*-wave latency occurs, and *a*-waves also become more prominent.

DISCUSSION

Shape of the ERG waveform depends upon relative contributions of scotopic and photopic signals being propagated to inner retinal layers. In duplex retinæ such as in the human, for example, the (*b*-wave is often composed of two components (*b*₁ and *b*₂), with different latencies; the short latency *b*₁ component corresponds with photopic activity while the longer latency *b*₂ component corresponds with scotopic activity (Brunette 1969). The *b*₁ component can be isolated with the use of longer wavelength (i.e., red) stimuli while *b*₂ components can be isolated with shorter wavelength (i.e., blue) stimuli. In the Great Horned Owl recovery during dark adaptation was dominated by scotopic processes manifested by slow rising *b*-waves which were fairly broad and had relatively long latencies. Since stimulus parameters used in dark adaptation generally elicit scotopic activity primarily, a photopic *b*₁ component was not seen in this study during dark ad-

aptation. With different pre-adaptation and stimulus parameters a duplex retina ordinarily will demonstrate an early and transient photopic recovery indicated by *b*-waves with shorter latencies (dominated by the *b*₁ component) followed by scotopic recovery.

Higher intensity single-flash stimuli without a blue filter produced ERGs with more prominent *a*- and *b*-waves. *B*-waves were also narrower and had a shorter latency, suggesting the presence of a photopic component which was contributing to overall response. Higher intensity stimuli were presumably able to initiate a cone response. Change in amplitude and latency of the *b*-wave and appearance of the *a*-wave as stimulus intensity is increased were similar to results obtained from cat (Brown 1968; Niemeyer 1976), rabbit (Ikeda 1966) and horse (Wouters et al. 1980) retinæ. At low stimulus intensities the *b*-wave is broad and rounded and there is no *a*-wave, indicating primary activity produced by the scotopic system. At higher stimulus intensities the *b*-wave increases in amplitude and becomes steeper and more pointed. Also, *a*-waves become more prominent, indicating addition of a photopic component that contributed to overall response. In animals that have an essentially pure cone retina ERGs show an extremely high amplitude *a*-wave and very short latency *b*-wave composed almost exclusively of the *b*₁ component (Tansley et al. 1961). Addition of a blue filter also increased average latency of the *b*-wave, suggesting that the photopic contribution was "filtered" out and the major contribution to the waveform was from the scotopic system.

Results from the flicker procedure more convincingly demonstrate the existence of a cone component in the retina of these owls. Large differences in CFF from low to high intensities is an indication of a shift from scotopic to photopic functions. A one-to-one response seen at low intensities and low flicker frequencies was produced primarily by scotopic activity. Rods were following the individual flicker, having not yet exceeded their critical fusion frequency. Loss or fusion of the one-to-one response occurred at fairly low flicker frequency. At higher intensities the one-to-one response fused at significantly higher frequencies, an indication of a switch to photopic activity since cones possess a higher critical fusion frequency than rods (Armington 1974; Fishman 1975). Such results are quite common in animals known to have mixed retinæ, including humans (Armington 1974).

The ERG results confirm the expectation that the Great Horned Owl retina possesses a significant scotopic component. In addition a photopic component is present but is only evident with proper stimulus parameters. These results suggest that the Great Horned Owl retina is composed primarily of rods but also contains some cones as has been confirmed anatomically by previous light-microscopic observations (Oehme 1961; Fite 1973; Ault 1984).

The Great Horned Owl retina is dominated by scotopic processes which certainly impart an increased sensitivity to low light levels typically encountered. However, the owl is often active during the day and the few cones present may help mediate vision in more intense illumination of daylight hours. In a detailed study of optics and visual performance of the Tawny Owl (*Strix aluco*) Martin (1982) suggested that the resolving power of the eye of this owl and the pigeon (*Columba* sp.) were in fact very similar at photopic and mesopic luminances. The Tawny Owl has superior acuity to the pigeon at lower luminance levels, and although photopic acuity of both species are quite similar, acuity declines much faster in lower luminances for the pigeon than the owl (Martin 1982). Briefly stated, the pigeon by virtue of its optics and eye structure cannot function in lower luminance levels, while the owl by virtue of its optics and eye structure can function over a wide range of luminance from scotopic to photopic.

Additionally, specific neuroanatomical arrangements of photoreceptors contribute to spatial resolution and visual acuity in the Great Horned Owl. Foveal rods, which have a lower convergence ratio, give increased ability for point-to-point resolution at higher luminances, while non-foveal rods which have higher convergence ratios and higher absolute sensitivity may be serving this function at lower luminances (Fite 1973).

These observations, coupled with duplicity in retinal functioning revealed in this study, suggest that the Great Horned Owl is not only an effective nocturnal predator but is able to expand activity into the "diurnal realm" if needed.

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SHORT COMMUNICATIONS

SNOWY OWL NUMBERS ON TWELVE QUEEN ELIZABETH ISLANDS, CANADIAN HIGH ARCTIC

FRANK L. MILLER

Predominantly white plumage and relatively large body size, form and characteristic flight pattern, facilitate aerial surveys of the Snowy Owl (*Nyctea scandiaca*) on tundra islands of the Canadian High Arctic. Snowy Owls were recorded on nine central (July 1985) and three western (July 1986) Queen Elizabeth Islands, Northwest Territories, during Canadian Wildlife Service aerial surveys of Peary Caribou (*Rangifer tarandus pearyi*) and Muskoxen (*Ovibos moschatus*).

Bathurst, Alexander, Marc, Massey, Vanier, Cameron, Helena, Loughheed and Edmund Walker islands were surveyed by air between 10 and 25 July 1985 (Fig. 1A). Prince Patrick Island, Eglinton Island and Emerald Isle were surveyed by air between 4 and 13 July 1986 (Fig. 1B). Survey design consisted of systematically spaced, north-south orientated line transects at 6.4-km intervals. A Bell-206B "Jet Ranger" turbo-helicopter was flown approximately 90 m above ground level (agl) and at an airspeed of approximately 160 km/hr. A four-person survey crew was used: pilot, navigator and two rear-seat observers.

All four crew members spotted Snowy Owls. Rear-seat observers recorded the angle of depression from the horizontal plane to the position of each owl observed using a hand-held clinometer to calculate each owl's right angle horizontal distance from the helicopter. All clinometer readings were taken when the observer in the helicopter was at a right angle to the point where an owl first was seen. Snowy Owls already in flight or flushed during observations were classed as "flushed," and owls that remained perched were classed as "perched."

Strip transect boundary width was set at 6°: all readings of $\geq 6^\circ$ were designated as "on transect" and all readings of $\leq 5^\circ$ were designated as "off transect." Right angle horizontal distance from the helicopter to a Snowy Owl at a reading of 6° was 857 m (90 m agl/0.105, tangent of 6°). On this basis, "on transect" owls were within a strip transect 1.714 km wide, which yields an overall coverage of 27.3% of 20 855 km² in 1985 and 27.9% of 17 930 km² in 1986. Only "on transect" owl numbers were used in population and mean density estimates. Calculation of population estimates and mean densities and their associated statistics were done following procedures for analysis of data arising from systematic transect surveys (Kingsley and Smith 1981).

1985 SURVEY

In July 1985, 314 Snowy Owls were counted on nine islands (Fig. 1A) of which 81.2% were on transect (Table 1). Based on these numbers, I estimated that there were 932 Snowy Owls at a mean density of 45 owls/1000 km² on the entire survey area (Table 2).

Eighty-seven percent of the owls counted on transect were either in flight or took flight during observations. Owls appeared to flush in response to the oncoming survey helicopter. The remainder of owls counted remained perched during observations. No record of "flushed" versus "perched" owls was kept for the 59 Snowy Owls seen off transect.

Relatively low numbers of Snowy Owls counted on all islands except Bathurst prevent "among-island" or "within-island" statistical examination of densities and distributions on the overall survey area. Densities of Snowy Owls were highest on Ile Marc, Massey Island and north-western Bathurst Island (Tables 1 and 2). On a collective basis, numbers of Snowy Owls counted on Bathurst Island, compared to numbers counted on the other eight islands, was proportional to the two landmasses involved. Bathurst Island comprised 77.2% of the total landmass of the nine-island survey area in July 1985, and 84.7% of Snowy Owls counted on transect and 79.7% of the owls counted off transect were counted on Bathurst.

Snowy Owls were rather evenly distributed over large areas of Bathurst Island. However, the number of Snowy Owls seen "on transect" on northwestern Bathurst Island (Stratum I, Fig. 1A) was significantly greater ($P < 0.05$, $\chi^2 = 6.22$, $df = 2$) compared on a relative landmass basis to numbers of Snowy Owls seen "on transect" on northeastern Bathurst (Stratum II, Fig. 1A) and southern Bathurst (Stratum III, Fig. 1A) (Table 1).

Collared Lemmings (*Dicrostonyx torquatus*) were abundant over most, if not all, of Bathurst Island in July 1985. Lemmings were constantly underfoot in our field tent camp on central Bathurst and were seen at fuel caches on other parts of the island. Most burrows observed showed fresh signs of excavation. We also saw four Arctic Fox (*Alopex lagopus*) dens with pups on Bathurst Island, a positive sign of high lemming availability.

1986 SURVEY

Only three Snowy Owls were counted during the 1986 survey, although the landmass surveyed was 86% as large as that surveyed in 1985 (Fig. 1A, B). All three owls were on Prince Patrick Island: two were on transect and one

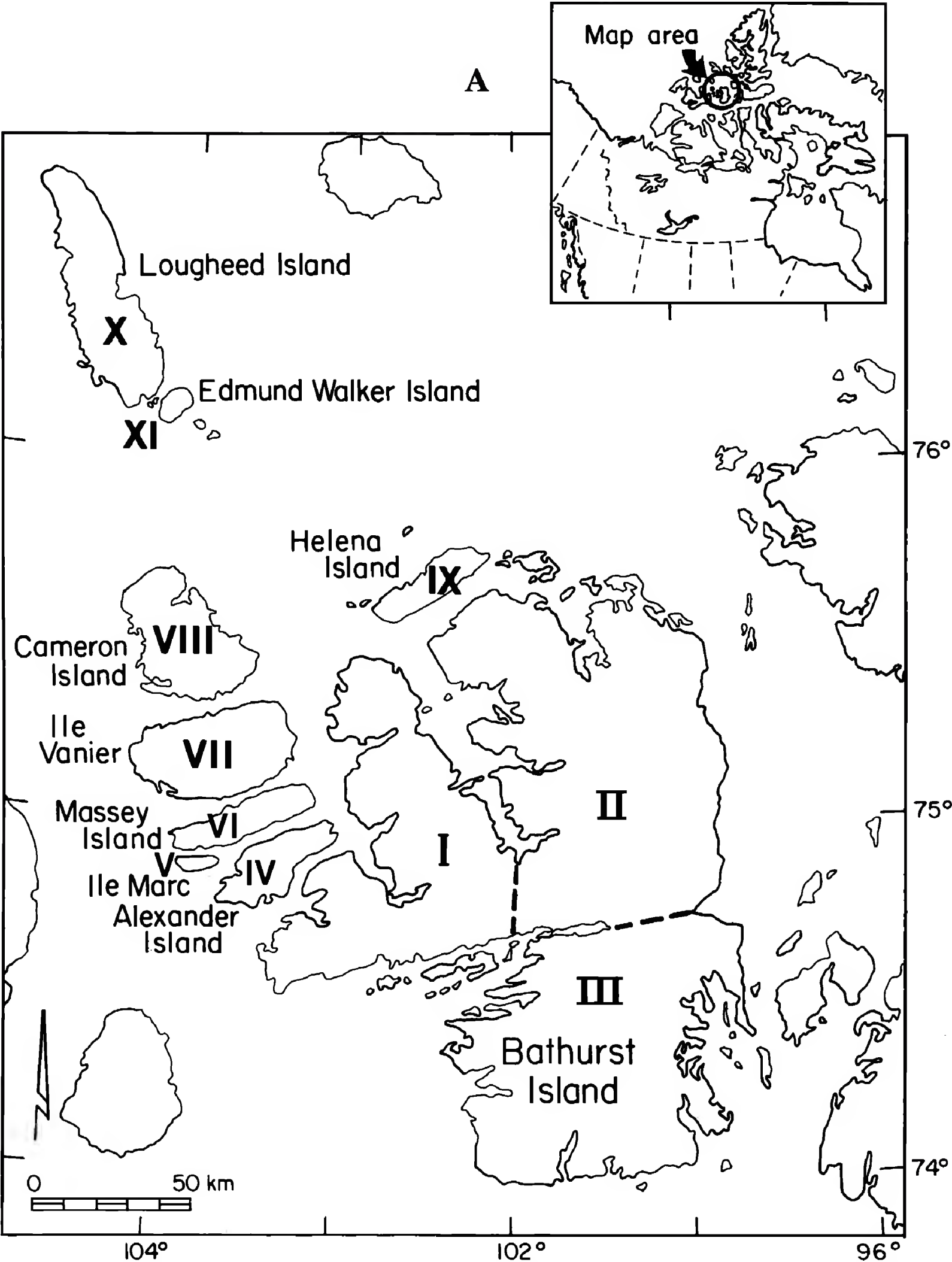


Figure 1. Location of Canadian High Arctic Islands where numbers of Snowy Owls were obtained by aerial survey. (A) nine central Queen Elizabeth Islands (11 survey strata), July 1985; and (B) three western Queen Elizabeth Islands (five survey strata), July 1986.

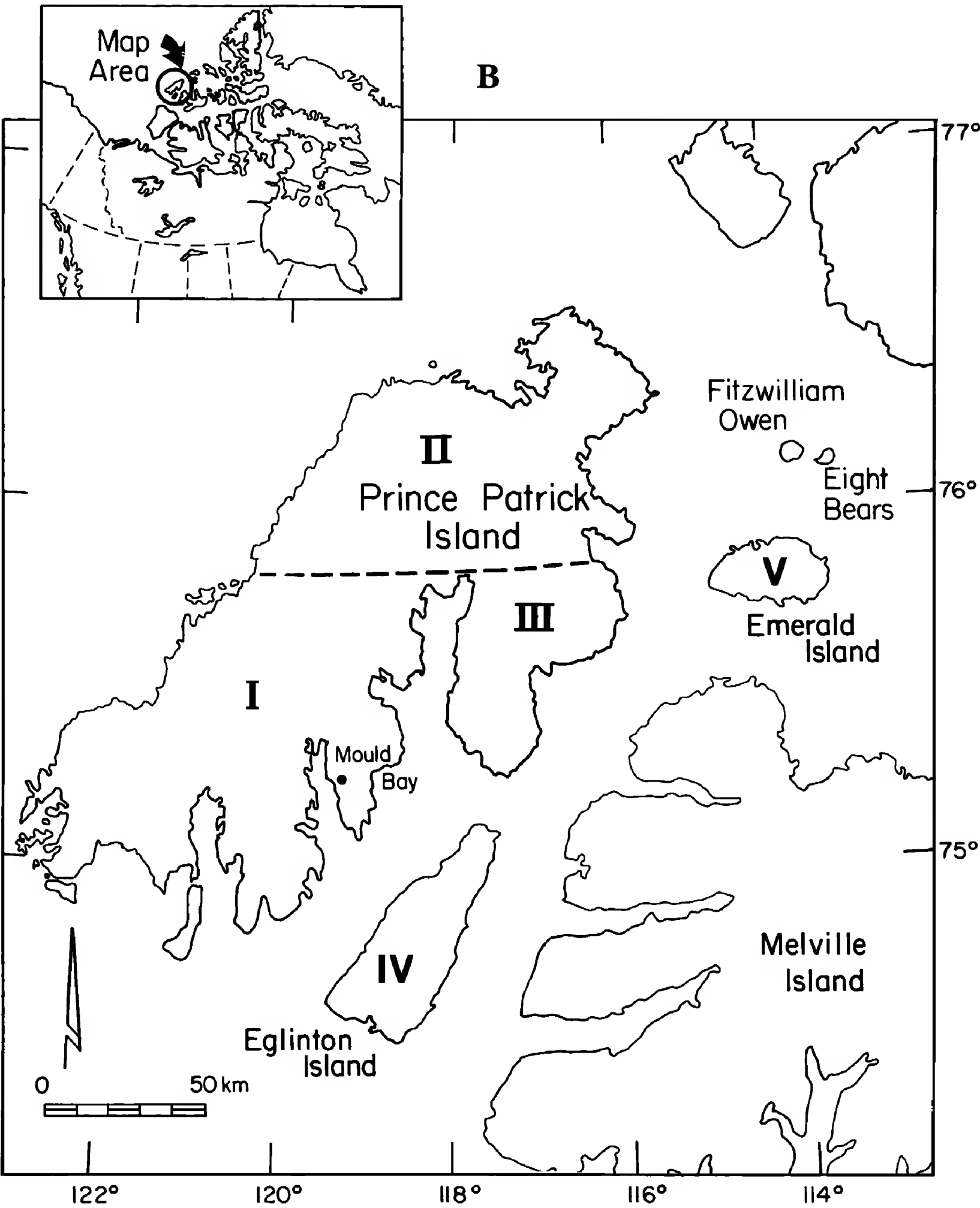


Table 1. Numbers and distributions of Snowy Owls seen during aerial survey of nine central Queen Elizabeth Islands, Canadian High Arctic, Northwest Territories, July 1985.

ISLAND (SURVEY STRATUM)		ON TRAN- SECT	OFF TRAN- SECT	TOTAL
Bathurst, NW	(I)	71	23	94
Bathurst, NE	(II)	80	10	90
Bathurst, S	(III)	65	14	79
Alexander	(IV)	7	4	11
Marc	(V)	1		1
Massey	(VI)	8	6	14
Vanier	(VII)	5	1	6
Cameron	(VIII)	13	1	14
Helena	(IX)	2		2
Lougheed	(X)	3		3
Edmund Walker	(XI)			0
Strata I-III		216	47	263
Strata IV-XI		39	12	51
Strata I-XI		255	59	314

was off transect. On this basis, I estimated only seven owls to be on the entire survey area and calculated a density of only 0.4 owls/1000 km² in July 1986.

In July 1986 the survey crew searched for lemmings or fresh signs in the base-camp area at Mould Bay, Prince Patrick Island, and in other areas each time the helicopter landed for refueling. No lemmings or fresh burrows were seen anywhere that was searched on the three-island complex (Fig. 1B). In addition five Arctic Fox dens were found, but none were active.

Tener (1963) counted only 13 Snowy Owls during an aerial survey of 7.8% of Bathurst, Alexander, Massey, Vanier and Cameron islands between 19 June and 7 July 1961. Assuming 13 Snowy Owls were counted "on transect," an extrapolated estimate would yield 166 owls total on five islands. On this basis the number of Snowy Owls on the five islands was at least 5.5× greater in 1985 than in 1961. On 23 July 1961 Tener (1963) counted 10 Snowy Owls on Prince Patrick (4.2% coverage), six owls on Eglinton (5.9% coverage), and four owls on Emerald (9.2% coverage) on 24 July 1961. Assuming all 20 owls counted in July 1961 were on transect, the resultant estimate would be 384 owls versus only seven owls estimated in July 1986.

Magnitudes of annual variation in Snowy Owl numbers is best illustrated with data from Eglinton Island. Miller et al. (1975) counted five, 56 and 27 Snowy Owls and estimated 20, 111 and 54 owls on Eglinton in summers of 1972, 1973 and 1974, respectively. Yet not a single owl was counted in summer 1986.

The importance of lemmings to Snowy Owls is well

Table 2. Mean densities and numbers of Snowy Owls on 11 survey strata of nine central Queen Elizabeth Islands, Northwest Territories, July 1985, obtained by aerial survey.

AREA SURVEY STRATUM (ISLAND)		STRATUM SIZE (KM ²)	AREA SURVEYED (KM ²)	OWLS/1000 KM ²		POPULATION ESTIMATES	
				MEAN ^a	95% C.I. ^b	ESTIMATE ^a	95% C.I. ^b
I	(Bathurst, NW)	4080	1113	64	55-73	260	224-297
II	(Bathurst, NE)	6650	1794	45	36-53	297	238-355
III	(Bathurst, S)	5360	1478	44	28-60	236	151-321
IV	(Alexander)	490	129	54	25-84	27	12-41
V	(Marc)	56	15	67	0-719	4	0-40
VI	(Massey)	440	122	66	29-102	29	13-45
VII	(Vanier)	1130	303	16	5-28	19	6-31
VIII	(Cameron)	1060	293	44	20-69	47	21-73
IX	(Helena)	220	90	22	9-54	5	0-12
X	(Lougheed)	1300	352	8	2-19	11	0-24
XI	(Edmund Walker)	69	17				
I-III		16 090	4386	49	43-56	793	689-896
IV-XI		4765	1320	30	23-36	141	109-173
I-XI		20 855	5705	45	40-50	932	827-1038

^a The discrepancy of three owls (935) obtained by the summation of 11 individual strata (I-XI) versus the single calculation of 932 owls for strata I-XI is a rounding error. Also, use of whole number values for mean densities prevents exact recalculation of estimates from tabular material: e.g., (survey area × mean density = estimate) therefore, (20 855 × 45/1000 = 938) but when actual mean density of (0.0447 owls/km²) is used (20 855 × 0.0447 = 932). Note that recalculation of any mean density values requires that the tabular value first be reduced to a unit of one (km²).

^b Negative values reported as zero (0).

known. One obvious difference between the survey areas was the high numbers of lemmings present in July 1985 and the extremely low number apparently present (none counted) in July 1986. Likely, high numbers and widespread distribution of lemmings accounted for the commonness of Snowy Owls throughout much of the survey area in 1985 compared to 1961. However, lemming populations can be asynchronous on adjacent islands. For example in summer 1958 lemmings were abundant (approx. $\frac{1}{50}$ m²), and so were Snowy Owls on Prince of Wales Island, while no lemmings or owls could be found on Somerset Island 40 km away (T. W. Barry, pers. comm.). Absence of lemmings on the July 1986 survey area could account for the difference in Snowy Owl numbers in 1961 vs. 1986.

Unfortunately, I have no knowledge of what proportion of the surveyed area in each year was suitable nesting habitat or what proportion of the owls seen were associated with nests. In general plant cover is relatively sparse on the western half of Prince Patrick Island, the northern tip of Eglinton Island, and the southern end of Loughheed Island compared to the remainder of the areas surveyed in 1985 and 1986.

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A NEW METHOD TO SELECTIVELY CAPTURE ADULT TERRITORIAL SEA-EAGLES

ANTHONY L. HERTOOG

Adult eagles are difficult to capture in their territory or breeding range. In northern Australia adult territorial White-bellied Sea-eagles (*Haliaeetus leucogaster*) were often attracted to capture sites but usually perched and watched from nearby. However, some came to bait but only after non-target birds had disturbed the trap. Therefore, a new, manually-operated, single-noose system was developed and compared with trapping success of three conventional methods (i.e., cage traps, cannon netting and eagle-triggered multi-noose systems). The new capture system requires a concealed hide (e.g., a camouflaged vehicle) located 200 m from the bait. One operator remains at the hide while another prepares the capture system. A capture site (approx. 2 m²) clear of debris and vegetation is chosen well within an eagle's territory and in view of the hide.

Bait (normal fish prey) is aligned such that the head is facing away from the hide and secured with two 300 × 10 mm steel pegs (Fig. 1). Alignment is important because eagles usually grasp the bait lengthwise with both feet, and the noose when sprung easily snares the eagle's legs from the side; otherwise the noose may slide up the back of the eagle.

Vegetation is cleared next to the hide, and one end of a 5 m length of 10 mm surgical tubing with a loop tied at each end is pegged to the ground next to the hide entrance. The other end is stretched and pegged beyond the hide (Fig. 1). A fishing reel (120 mm dia) bolted to flat steel (300 × 50 × 8 mm thick) is placed on the ground next to the tubing at the farthest point from the bait (Fig. 1a). The reel held 250 m of 18 kg monofilament line and

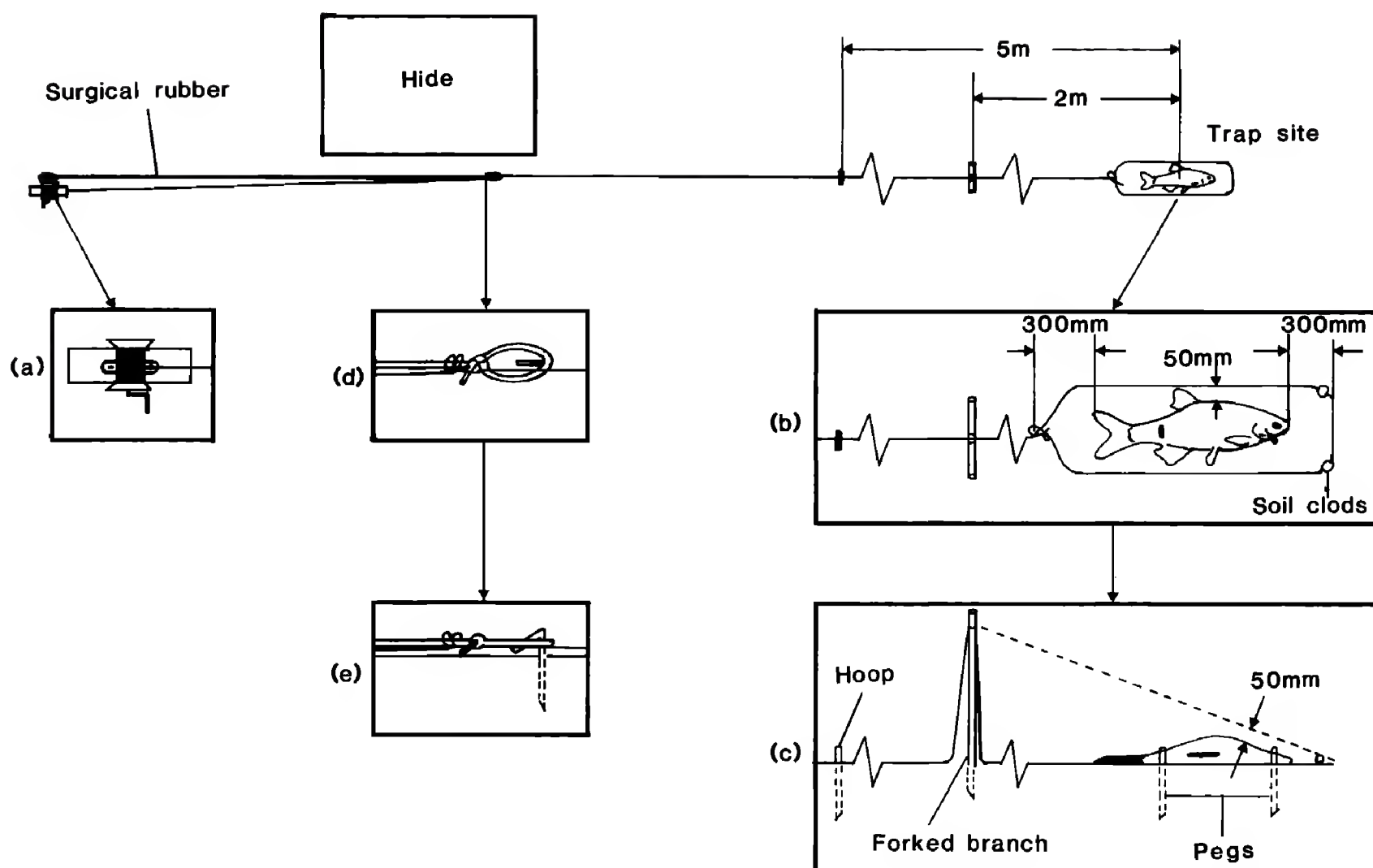


Figure 1. Diagram (not to scale) of manually-operated single-noose system. (a) enlarged plan view of reel; (b) enlarged plan view of capture site; (c) enlarged side view of capture site to illustrate the angle of line pull; (d, e) enlarged views of trigger mechanism.

2.5 m of 18 kg black, plastic-coated, trace wire to form a pre-prepared noose using a running slip knot (Jenkins, M. A., *N. Am. Bird Band.* 4(3):108–109, 1979). Trace wire is multi-stranded and lays flat on the ground compared to monofilament line and is thus less likely to be disturbed by non-target animals. The noose is carefully placed around the bait so that the free end is 300 mm in front of the head of the bait and held at two corners with small clumps of soil (Fig. 1b). Sides of the noose are placed 50 mm from and parallel to the bait, and a running slip knot is placed flat on the ground 300 mm behind the tail of the bait directly in line with the hide. A small forked branch, approximately 18 mm dia \times 750 mm length, is pushed into the ground 2 m from the center of the noose area, and the monofilament line lays through the fork. Fork height is adjusted so that the closest point of an imaginary line from the fork to the free end of the noose is about 50 mm above the front of the bait (Fig. 1c), which prevents the noose from snagging on the bait. Line is lightly held close to the base of the branch with small pieces of twig as is the remainder of the noose to minimize disturbance by non-target animals. Combined weight of twigs does not exceed that of soil clumps; otherwise the line will pull along the ground and become entangled with the bait. A steel hoop was pegged across the main line about 5 m

from the bait to prevent a captured bird from rising with the line attached.

At the hide the monofilament line is tied behind the knot in the bait end of the tubing using a clove hitch knot, and the peg holding the tubing is lifted slightly and turned 180° to allow the tubing to slip off easily when pulled upwards (Fig. 1d, e). The system is operated from the hide using a piece of 4 mm fencing wire bent 90° at one end and looped to form a handle at the other. The bent end is placed under the tubing just behind the front peg so that when pulled up the tubing is released from the peg which also pulls the line and causes the noose to quickly tighten around an eagle's legs. Attempts to escape further tightens the noose and injury is minimized by the elasticity of the tubing. A captured bird is easily subdued with a hand-held catching net.

When the system is ready, the person at the bait end moves to a concealed position well away from both the trap site and the hide in an attempt to deceive eagles that the area has been vacated; radio contact is maintained with the operator in the hide. Other birds, especially Black Kites (*Milvus migrans*) and Whistling Kites (*Haliastur sphenurus*), often gather and alight on or near the bait often causing a target eagle to attempt to pick up the bait or to scatter other birds. In either case the eagle usually returns

Table 1. Comparative capture success for White-bellied Sea-eagles using four capture methods.

METHOD	NO. TRAP-DAYS		NO. EAGLES CAPTURED		% SUCCESS ^a		
	TOTAL	WITHIN TERRI-TORY ^b	TOTAL ^c	TARGET EAGLES ^d	ALL EAGLES	TARGET EAGLES	
						TOTAL	WITHIN TERRI-TORY
Manually-operated single-noose system	13	6	5	4	0.38	0.31	0.67
Eagle-triggered multi-noose system ^e	17	9	1	1	0.06	0.06	0.11
Cannon net ^f	19	16	14	1	0.74	0.05	0.06
Cage trap ^g	56	15	4	0	0.07	0	0

^a No. per trap-day.
^b Excludes trap-days when eagles not seen or sites disturbed by non-target animals.
^c Juveniles, target and transient adults.
^d Adults which maintained a fixed year-long territory.
^e Modeled after Wegner, W. A., *J. Wildl. Manage.* 45(1):248-250, 1980.
^f See Addy, C. E., U.S. Fish and Wildl. Serv., Laurel, MD, 164 pp., 1956.
^g Cage traps (3 × 2 × 2 m high) were positioned for three months and baited for an average of four days. Together such a trapping attempt constituted one trap-day.

quickly and lands on or near the bait. Once an eagle is standing on the bait and feeding, the operator waits until the eagle lifts its head and only then triggers the system. In this study target eagles were adults which maintained fixed year-long territories rather than transient adults or juveniles. Significantly more target eagles were captured with the manually-operated noose system than with the eagle-triggered noose system ($P < 0.05$), cannon netting ($P < 0.01$) or cage traps ($P < 0.01$) (Fisher Exact Probability Test, Table 1). Capture success for all eagles (i.e., target, adult transient, juvenile) using the manually-operated noose system was also significantly greater than that using the eagle-triggered noose system ($P < 0.05$) and cage traps ($P < 0.01$), but not for cannon netting.

Baited cage traps are commonly used to capture birds (Day et al., *Wildlife management techniques manual*, 4th Ed. The Wildl. Soc., Washington, DC, 1980) and need little modification for raptors. In northern Australia cage traps have been used successfully in capturing Black Kites and Whistling Kites (A. Hertog, unpubl.; J. Estbergs, pers. comm.), but not White-bellied Sea-eagles. In 56 trap-days in areas where eagles were known to frequent, only four were captured (seven percent success) and none were target eagles. Cannon netting was very successful for juvenile and adult transient eagles with a 74% capture success in 19 trap-days. Only one target eagle was captured in 16 trap-days (six percent success). Although attracted to the vicinity of the trap site, target eagles tended to be wary of the net which was difficult to conceal.

An eagle-triggered noose system was set 17 times but only one target eagle was captured (six percent success). Failure was due to disturbance to the noose by eagles ($N = 3$) or capture/disturbance by Whistling Kites ($N = 5$).

Even when those disturbance data were excluded from results capture success was still poor (11%). In 13 trap-days five eagles were captured (38% success) using my new, manually-operated capture system, and two were missed because the trap was triggered prematurely by the operator. Other failures were due to the absence of adults at the trap site ($N = 3$) and disturbance at the trap site by mammals and reptiles. Excluding these data, capture success was 67% for four target eagles. Apart from being superior to other conventional trapping methods, my system has the advantages of being inexpensive, quickly set up, and easily concealed. In addition birds can be selectively captured (i.e., specific sex, age, status, species) thus making the technique useful in studies with other raptors.

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NORTHERN CARDINAL HEAD ATTACHED TO THE TOE OF A SHARP-SHINNED HAWK

THOMAS W. CARPENTER AND ARTHUR L. CARPENTER

On 16 May 1986 while using mist nets to capture and band migrant hawks at Whitefish Point, Chippewa County, Michigan, we captured an immature male Sharp-shinned Hawk (*Accipiter striatus*) with the head of a Northern Cardinal (*Cardinalis cardinalis*) attached to its left hallux (hind toe). The cardinal had apparently clamped its beak tightly on the hawk's toe. Both the head and toe broke off together when we untangled the hawk. The head was very necrotid and evidently had been attached to the hawk's toe for a considerable length of time.

The hawk was in average condition (wt = 101.2 g). Average weight of 184 immature male Sharp-shinned Hawks we banded at Whitefish Point during the springs of 1985–87 was 100.2 g (range = 75.7–125.9 g; Carpenter

and Carpenter, pers. obs.). Unusual injuries have been previously reported for the Sharp-shinned (Kelley and Kelley, *Wilson Bull.* 81:209–210, 1969; Evans, *Auk* 94: 585–586, 1977) but none of the type just described.

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Non-releasable Animal Placement Program (NAPP)—The Non-releasable Animal Placement Program is a computer-based information system for non-releasable species of mammals, birds, reptiles and amphibians. The purpose of the program is to maintain a clearinghouse for wildlife professionals who deal with non-releasable, permanently injured or imprinted animals and placement of surplus animals into various wildlife programs throughout North America. A monthly report is published listing all available and requested animals. Subscription fee for the NAPP is \$10.00/yr. There is no charge to list or request an animal. For additional information contact **NAPP, Animal Rehabilitation Center, Inc., 449 Edgefield Lane, Midlothian, Texas 76065.**

THE JOURNAL OF RAPTOR RESEARCH

INDEX TO VOLUME 21

COMPILED BY JIMMIE R. PARRISH AND F. RUTH BECK

The Officers and Board of Directors of the Foundation have approved the production of a 20-year index of the Foundations publications. Subsequent yearly indexes will serve as a continuum to the 20-year volume with additional updates provided as necessary. Scientific names follow the A.O.U. checklist where appropriate for avian scientific names, and all others follow the most current sources available.

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